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A LIMITED ANALYSIS OF A NEW AMMUNITION CONCEPT FOR POTENTIAL FUTURE RIFLE APPLICATION

Richard Kwatnoski, et al

Frankford Arsenal
Philadelphia, Pennsylvania

June 1973

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by

RICHARD KWATNOSKI
ROBERT McHUGH

D D C
AUG 15 1973

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Fumer						
Burst-fire						
AR-Shape						
AR-Bullet						

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ABSTRACT

An analytical study was conducted by the Ballistics and Analytics Branch, Frankford Arsenal, for the purpose of developing a new, low engineering risk, low impulse ammunition concept as a potential candidate for the Future Rifle System (FRS). The ammunition for this new system, designated as Future Ammunition for Burst-Rifle Launch (FABRL), was analytically developed as a 37.1 grain, AR2 shape, 5.56 mm projectile with the same muzzle velocity and trajectory as the standard 5.56 mm M193 projectile. A large number of candidate FABRL designs were generated and analyzed, and several of the designs appear very promising for meeting required performance criteria for the rifle role. In addition, one design could be considered for both the rifle and machine gun roles.

FOREWORD

The contributions of Mr. Richard Grant, K5100, in the preparation of the drawings and curves for this report are gratefully acknowledged.

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INTRODUCTION

In February 1971, the Ballistic Research Laboratory (BRL) published the results of a comprehensive study of the ballistic properties of a broad spectrum of projectile shapes (Figure 1) which included various calibers, velocity levels, and material densities.[1] A drag-reducing tracer (or "fumer") was also studied as a promising method for reducing projectile base drag. The projectile that generated the most interest was an artillery shape designated as the AR2 shape. This projectile in 5.56 mm is made from copper plated steel and weighs the same as the standard 5.56 mm, 55 grain M193 ball bullet (Figure 2). The AR2 shape was of interest because of its favorable drag characteristics which are significantly superior to the standard M193 bullet.

Considerable attention has been given to examining the feasibility of utilizing the AR2 shape projectile for the Squad Automatic Weapon System (SAW), where long range performance requirements have been documented. However, the interest that prompted the design study presented herein was based on determining the feasibility of utilizing the AR2 shape projectile for shorter range applications, such as the Future Rifle System (FRS).

CONCEPT ANALYSIS

An analytical study was undertaken by Frankford Arsenal for the purpose of developing a new concept as a potential candidate for the future rifle system. This new concept has been designated as Future Ammunition for Burst-Rifle Launch (FABRL). This study presents the merits of trading off a portion of the benefits attainable by utilizing the low-drag AR2 shape for a reduced weight, low-impulse, burst-fire rifle system. As with any systems design study, certain constraints must be established. The initial constraints applied to this study are as follows:

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[1] L. C. MacAllister, et al, "A Compendium of Ballistic Properties of Projectiles of Possible Interest in Small Arms," Ballistic Research Laboratories Report No. 1532, February 1971.

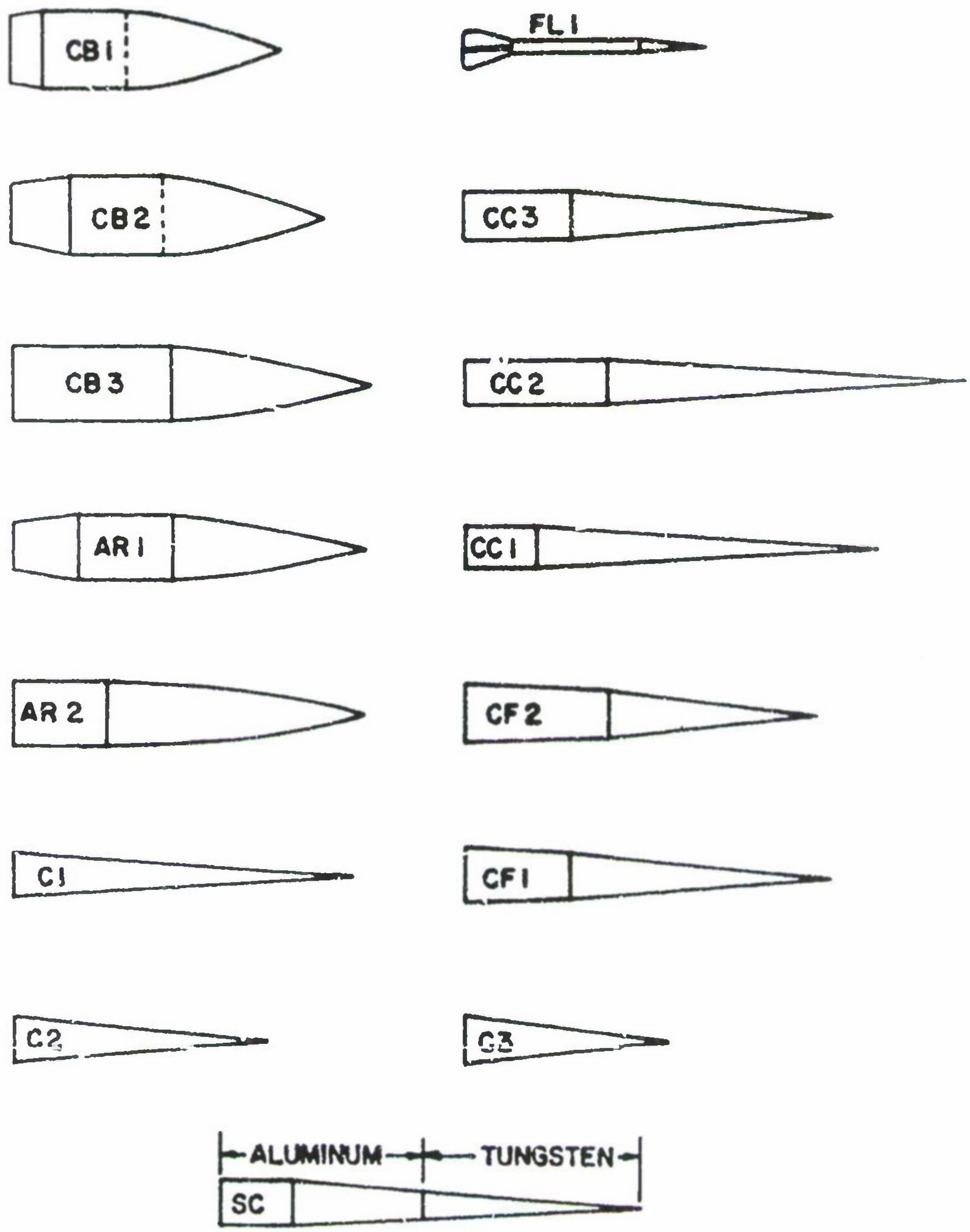

Figure 1. Projectile Shapes Studied by Ballistic Research Laboratories

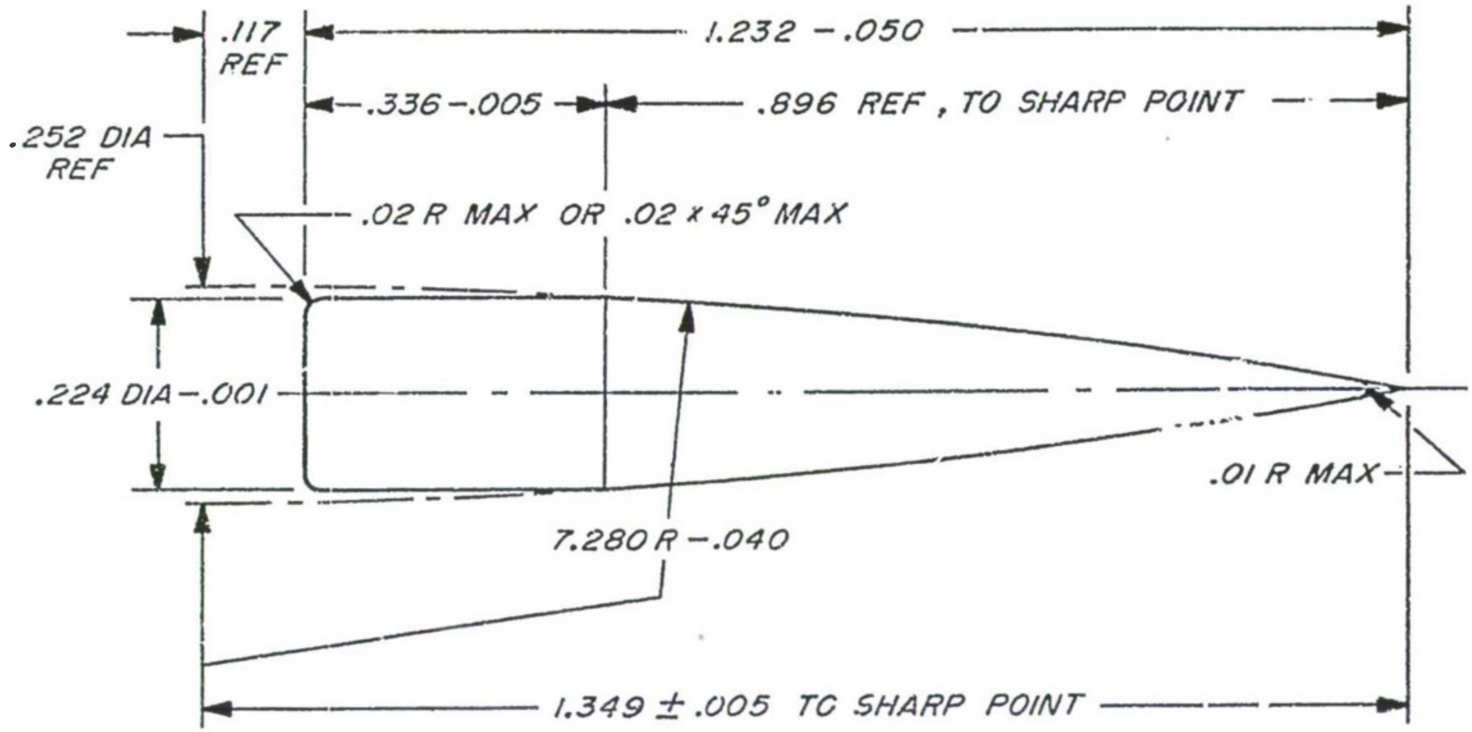

Figure 2. 5.56 mm AR2 Shape Projectile

1. 5.56 mm caliber,
2. 18.6 inch barrel travel,
3. Trajectory comparable to the M193 ball bullet, and
4. Muzzle velocity of 3270 fps (same as the M193).

The first and second constraints were based upon considerable interest in utilizing the M16A1 rifle or its basic mechanism for a future rifle. The last two constraints were based upon the User's acceptance of the performance characteristics of the M16A1 rifle.

The exterior ballistic parameters for the AR2 shape 5.56 mm projectile were calculated from results of actual firings conducted by BRL.[2] Using these parameters, the analysis indicated a required bullet weight of 37.1 grains to meet initial constraints 2 and 3 mentioned above. This represents a 33 percent weight reduction from the standard M193 ball bullet or copper plated steel AR2 shape bullet. Interior ballistic parameters for the FABRL system were calculated according to standard techniques.[3] Recalling that the FABRL is to be a low impulse system, interior ballistic parameters were generated with an additional constraint that the muzzle impulse not exceed 0.80 pound-seconds.

The results of exterior and interior ballistic calculations and other parameters of interest are shown in Table I. Information for the standard M16A1 system is also shown in Table I which also illustrates several important advantages of the FABRL concept over the standard M16A1 system. The FABRL concept could result in a considerably lighter system while still maintaining the same muzzle velocity and trajectory as the M193 ball bullet. The required chamber pressure of 39,500 psi could enhance the feasibility of utilizing lightweight case materials for a future system. Even if a brass case was required for the FABRL cartridge, overall cartridge weight should be reduced by approximately 30 percent from that of the 5.56 mm M193 cartridge.

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[2] M. J. Piddington, T. H. Oertel, E. L. Herr, and W. J. Bruchey, "Experimental Ballistic Properties of Selected Projectiles of Possible Interest in Small Arms" (U), Ballistic Research Laboratories Memorandum Report No. 2194, June 1972. (CONFIDENTIAL)

[3] "Interior Ballistics of Guns," Army Materiel Command Pamphlet AMCP 706-150, February 1965.

TABLE I.
Ballistic and Physical Parameters

Parameter	FABRL System AR2 Projectile	M16 System M193 Projectile
1. Caliber	5.56 mm	5.56 mm
2. Muzzle velocity	3270.0 fps	3270.0 fps
3. Projectile weight	37.1 gr	55.0 gr
4. L/D ratio	5.5	3.3
5. Ballistic coefficient (C_7)	0.126	0.126
6. Form factor	0.845	1.241
7. Barrel travel	18.6 in.	18.6 in.
8. Charge weight	15.0 gr	28.5 gr
9. Average peak chamber pressure	39.5 kpsi	52.0 kpsi
10. Muzzle impulse	0.80 lb-sec	1.23 lb-sec

The most significant advantage of the FABRL is the relatively low muzzle impulse of .80 pound-seconds. This impulse level also compares favorably with the current Serial Flechette Rifle (SFR) and Serial Bullet Rifle (SBR) candidates for the future rifle program. Reduced impulse systems have experimentally demonstrated significant increases in hit probabilities. The reduced impulse levels of the FABRL system are attainable without reliance upon small bore systems and/or projectile-sabot assemblies. These are the primary factors for considering the FABRL concept as a low engineering risk for the future rifle program.

The major potential drawback of the FABRL is that it would have almost one-third less striking energy at any given range, when compared to the M193. However, incapacitation probabilities are a function of the energy transferred to the target and the hit probabilities. The increased hit probabilities of the FABRL system should offset the reduction in striking energy. Striking energy reductions could be offset further by increasing the percentage of energy transferred (efficiency) to a soft target.

PROJECTILE DESIGN AND MATERIAL CONSIDERATIONS

The exploratory development of the FABRL concept was initiated via a comprehensive design study, to generate a number of 37.1 grain, 5.56 mm AR2 projectile designs. The primary objective was directed toward establishing a projectile design capable of transferring a reasonable percentage of its energy in soft targets, while maintaining hard target penetration capability.

The projectile density required by the fixed weight and exterior configuration is relatively low, thus ruling out the utilization of conventional lead core (jacketed) and solid steel core (copper plated) projectiles. This restriction required the investigation of a number of materials for which little information is known about their lethal properties.

Also, since analytical capabilities for predicting lethality have not advanced sufficiently to provide adequate design criteria, the nature of this design approach is highly exploratory. Light and soft materials could behave favorably in soft targets, but the requirement for penetration of helmets with liners must also be considered.

This dual requirement led to consideration of a number of designs of hybrid construction, with steel considered as the primary material for maintaining helmet penetration capability. Depleted uranium was also considered, since its high density increases the amount of light material that can be used in a hybrid FABRL design. However, the potential problems associated with the use of depleted uranium may yield results which are purely academic.

Other dense materials, such as tungsten, tantalum, etc., were eliminated because of their high cost. Several of the hybrid designs generated to date employ plastic materials. Certain plastic materials have proven satisfactory for bullet engraving in rifled barrels. The average density for the plastic considered was 278 grains/inch^3 (the approximate density of polycarbonate).

Composite materials, such as plastic/metal powders, were also considered. The economy and production feasibility of these materials were demonstrated with the adoption of the Cartridge, Caliber 30,

Frangible, Ball, M22. The frangible material used for the M22 bullet was a lead/bakelite composite (50 percent each material, by volume). The density of the frangible material was fixed at 1189 grains/inch^3. Lead or iron powder could be used with the bakelite (or any other suitable plastic).

A summary of the materials considered and their respective densities is given in Table II.

TABLE II.
Materials and Densities Used in FABRL Design Study

Material	Density (gr/in.^{3})
Steel	1960
Lead	2846
Uranium	4402
Gilding metal	2226
Plastic	278
Composite (frangible)	1189

Within this broad, generalized, analytical design study, nine FABRL designs were generated. These are shown in Figures 3 through 11. The gyroscopic stability calculations are shown in Appendix A for each of the designs.

DISCUSSION

The FABRL design study presented herein is not meant to be a complete analysis of all the possible approaches, nor should these designs be considered final. However, an analysis of a broad spectrum of possibilities is presented. In addition, any number of new designs could be generated by using the information presented herein as a basis. The primary intent in early dissemination of this information is to express a receptiveness to comments or alternate design ideas from other agencies.

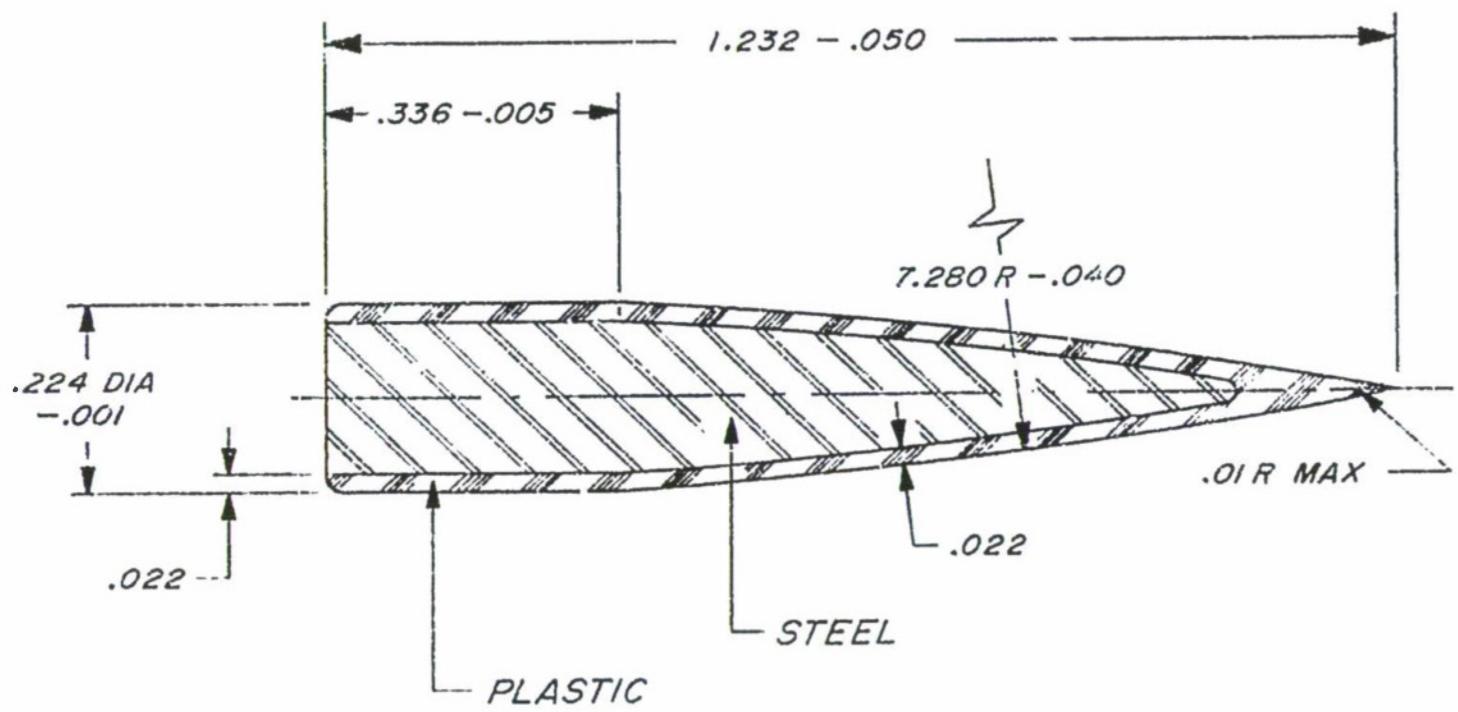

Figure 3. Future Ammunition for Burst-Rifle Launch (Design 1)

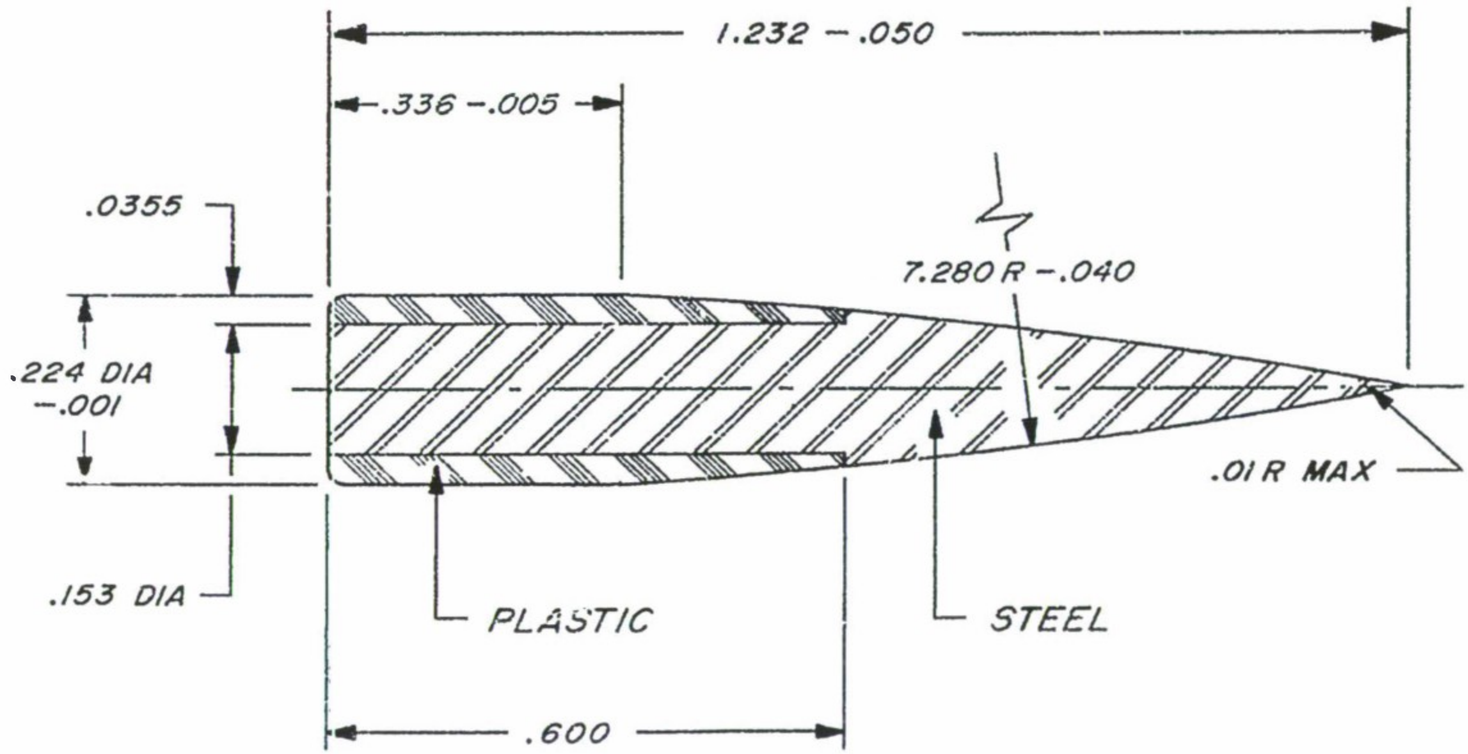

Figure 4. Future Ammunition for Burst-Rifle Launch (Design 2)

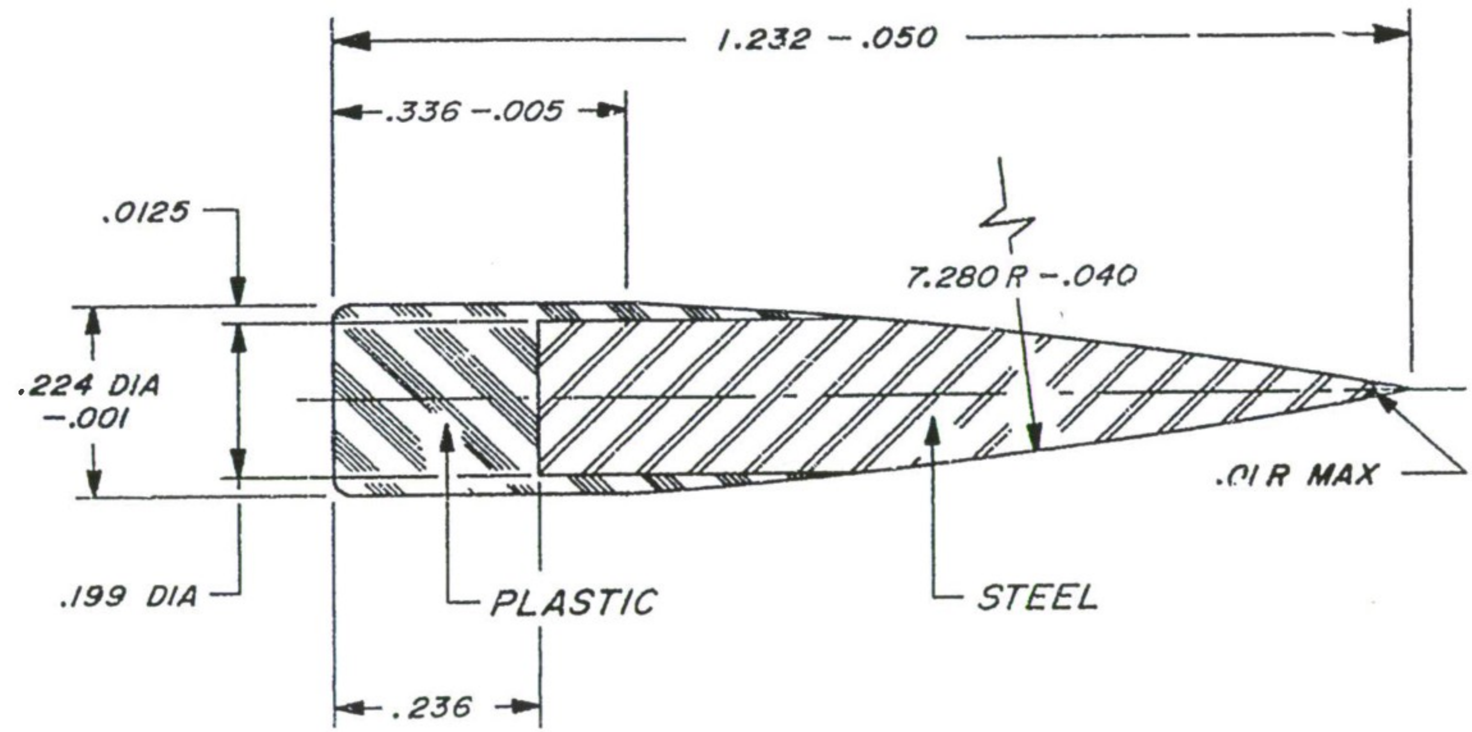

Figure 5. Future Ammunition for Burst-Rifle Launch (Design 3)

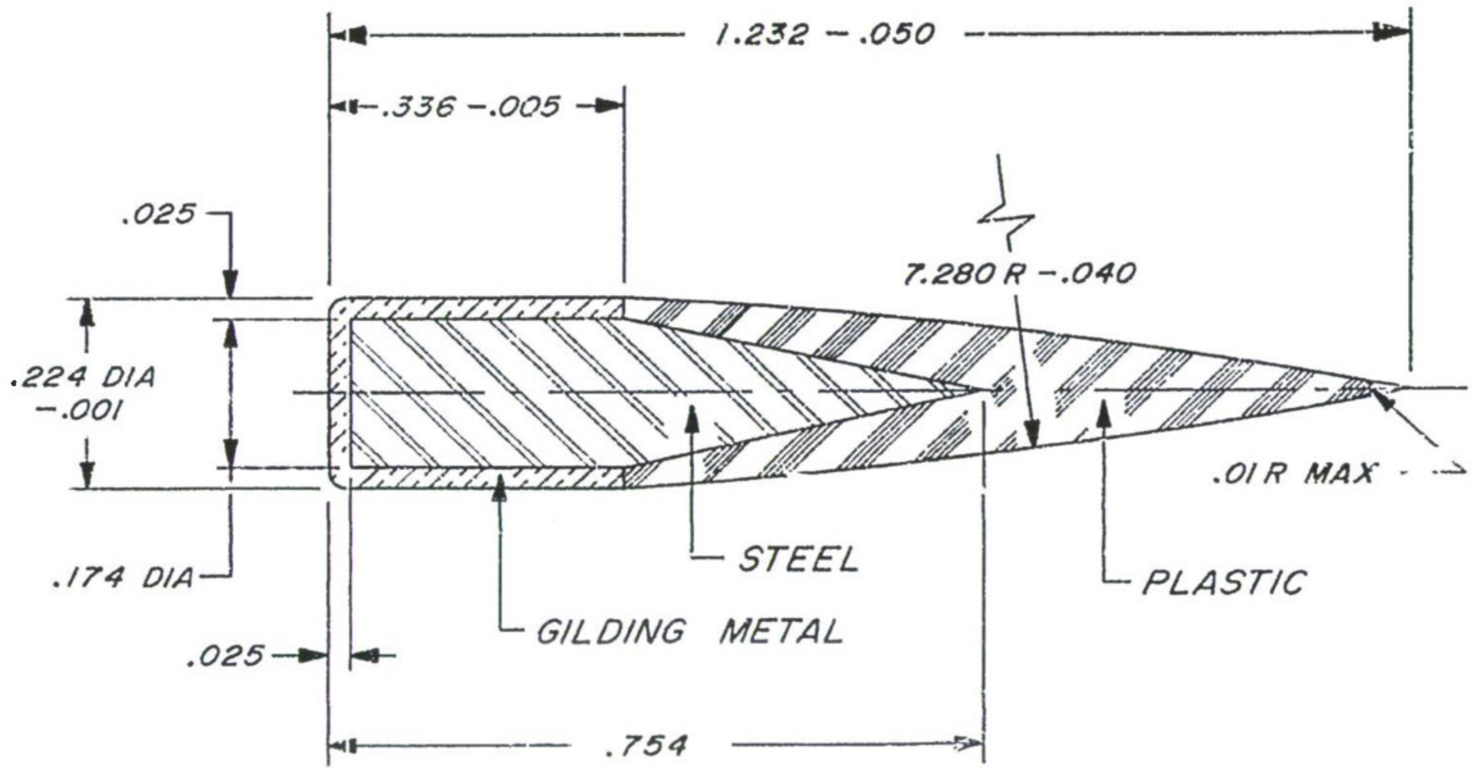

Figure 6. Future Ammunition for Burst-Rifle Launch (Design 4)

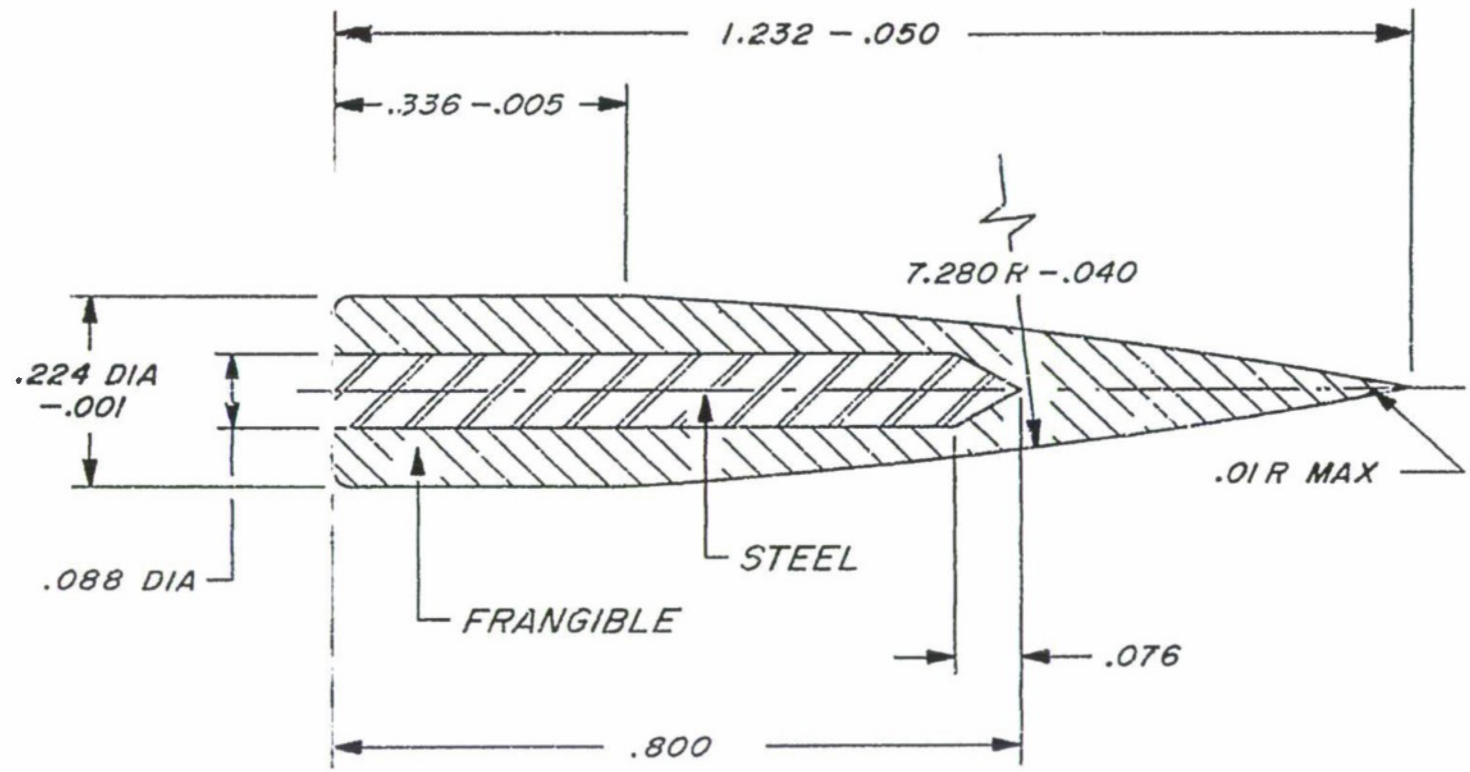

Figure 7. Future Ammunition for Burst-Rifle Launch (Design 5)

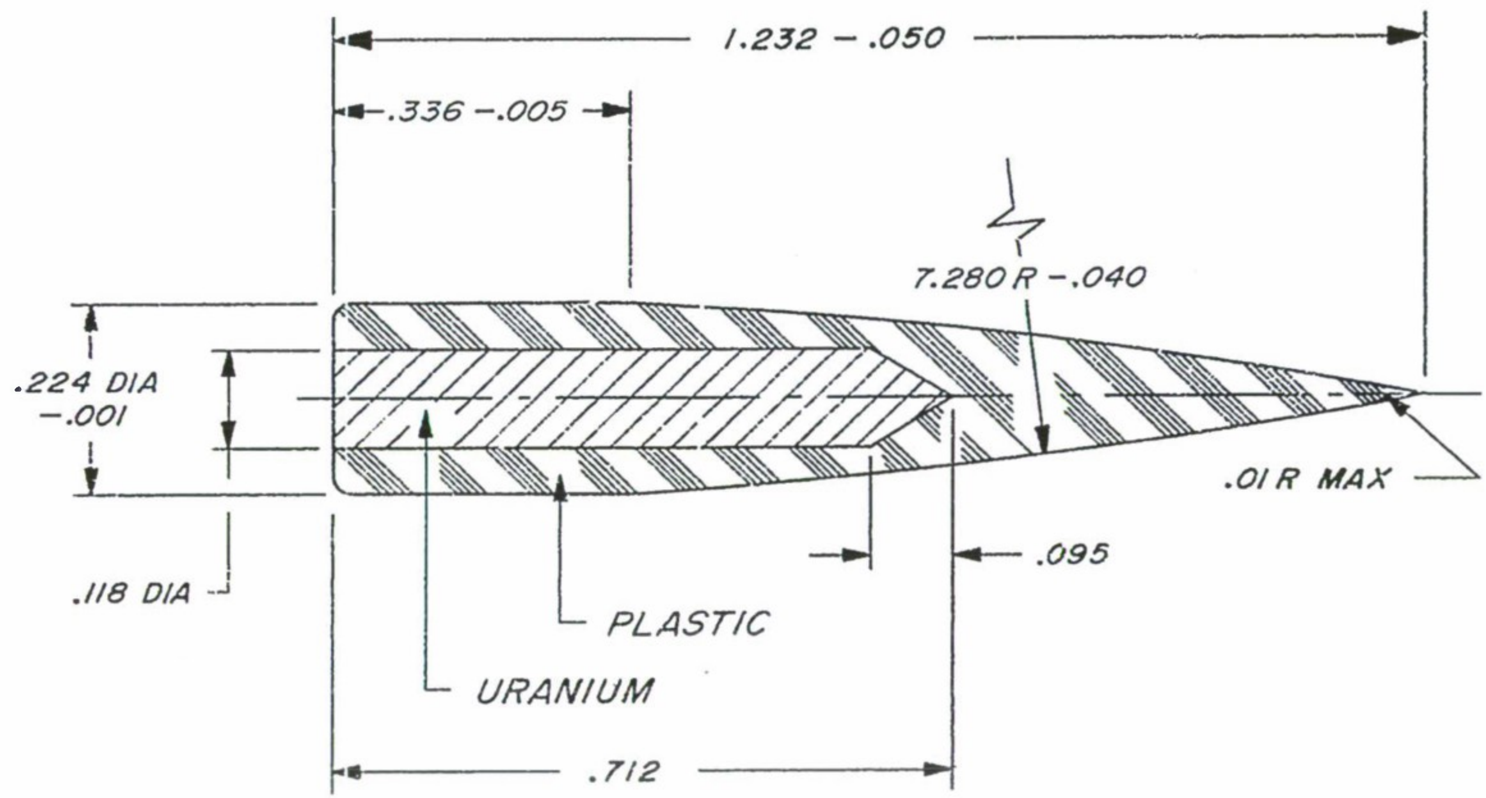

Figure 8. Future Ammunition for Burst-Rifle Launch (Design 6)

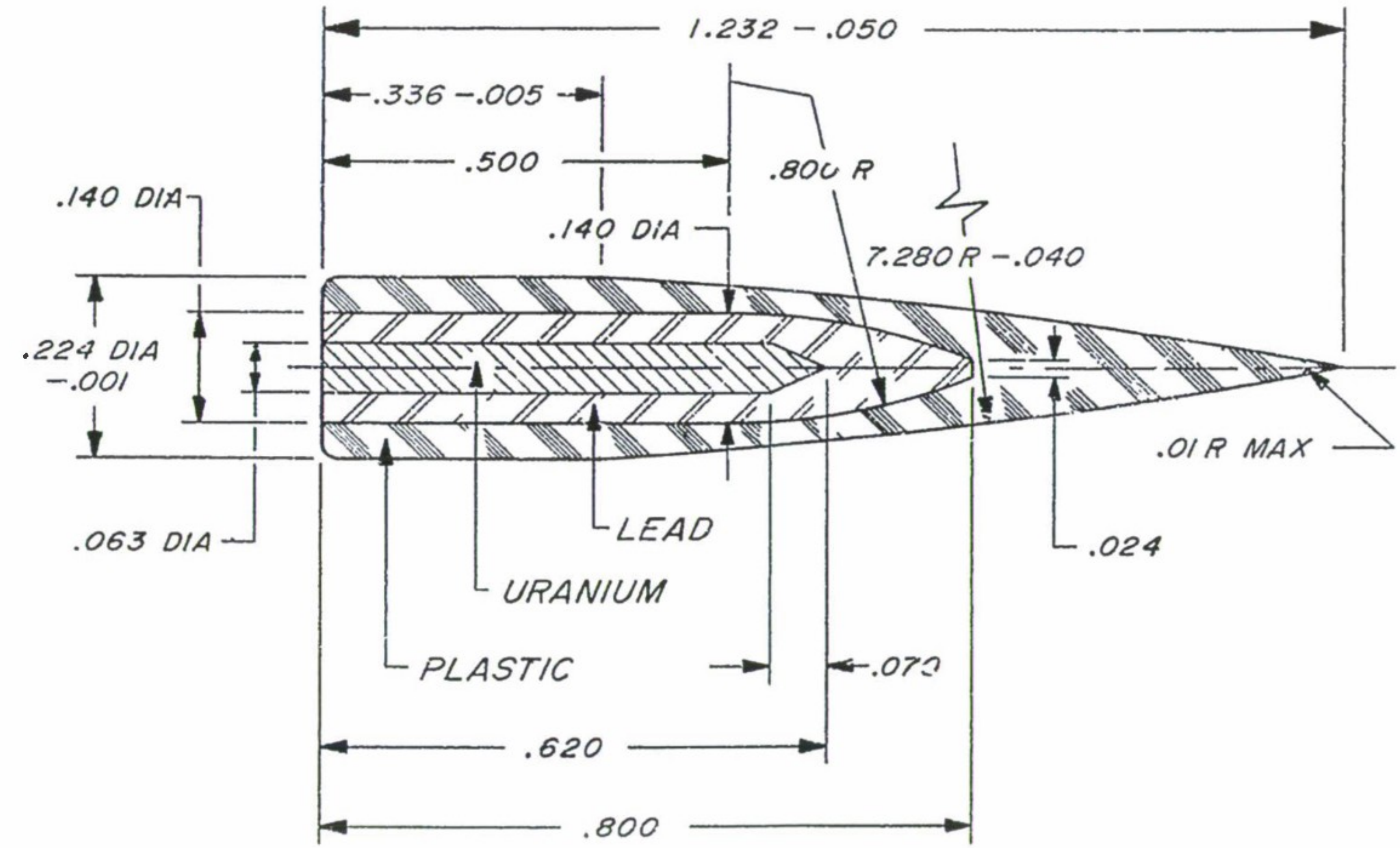

Figure 9. Future Ammunition for Burst-Rifle Launch (Design 7)

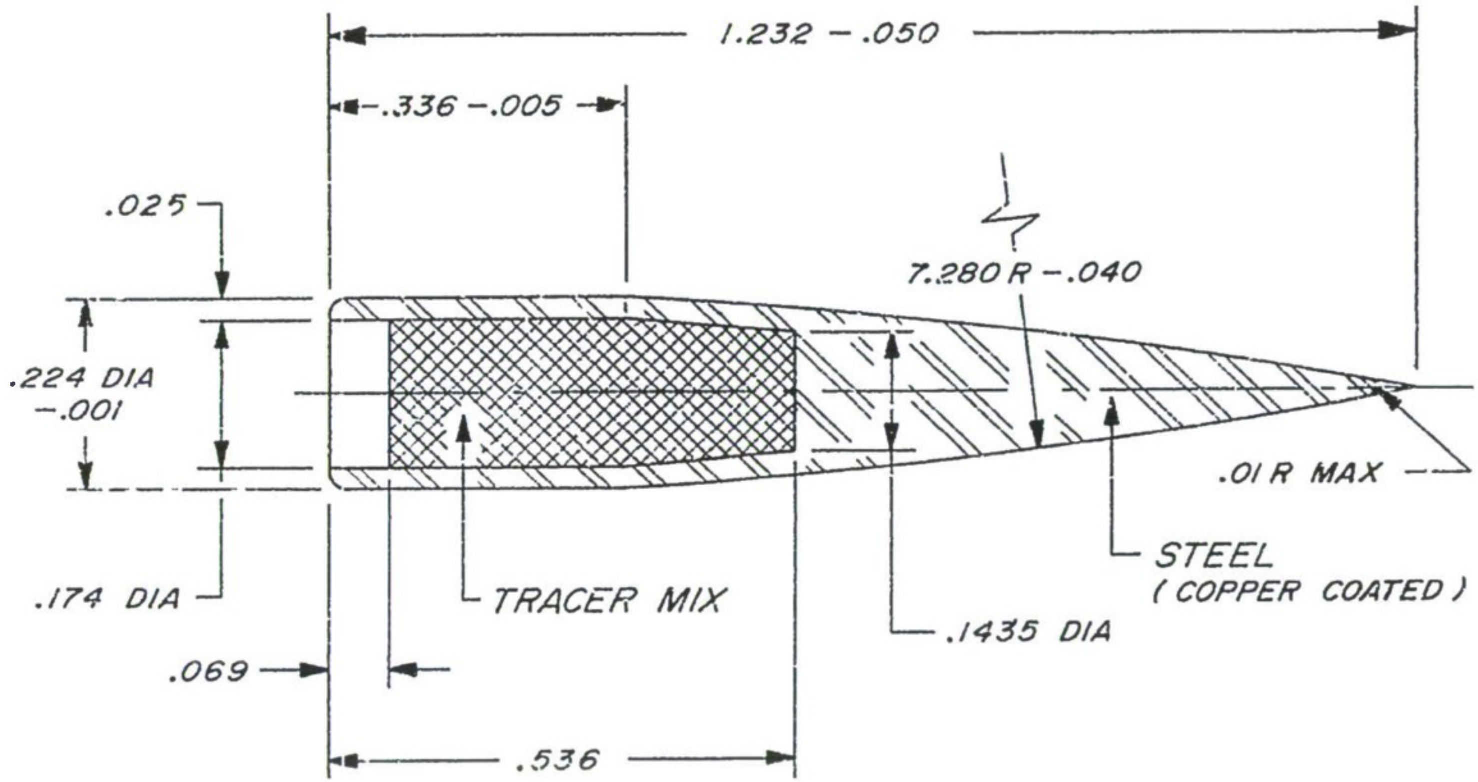

Figure 10. Future Ammunition for Burst-Rifle Launch (Design 8)

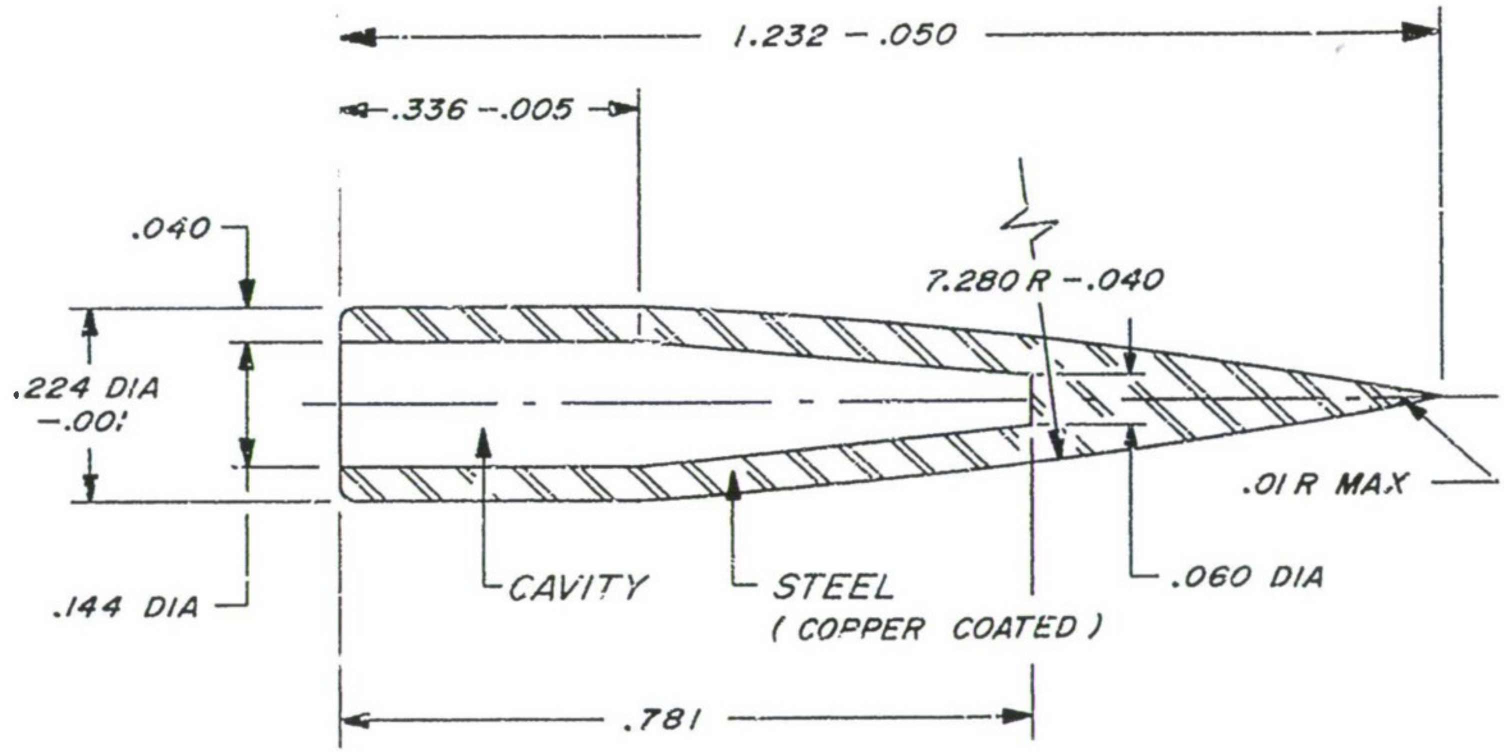

Figure 11. Future Ammunition for Burst-Rifle Launch (Design 9)

It is recognized that certain engineering problem areas are associated with a number of the FABRL designs. These problem areas will be addressed as development progresses. For example, the potential problem of securing a gilding metal cup on the base and bourrelet of design 4 (Figure 6) must be addressed. FABRL designs 2 (Figure 4) and 3 (Figure 5) are presented to illustrate extreme conditions of plastic thickness on the bourrelet of the steel bullet. A modification of these two designs may prove more desirable than either of the two extreme conditions.

Designs 1 (Figure 3) and 5 (Figure 7) appear to be satisfactory for experimental fabrication and testing. Designs 6 (Figure 8) and 7 (Figure 9) appear to present no major engineering problem areas, assuming the objections to the use of depleted uranium can be overcome.

Designs 8 (Figure 10) and 9 (Figure 11) would not present significant problems in the manufacture of experimental quantities. However, in mass production, the forming of cavities in solid steel and the necessity for copper plating could prove detrimental.

Design 8, incorporating a tracer (or "fumer"), would be especially interesting because of the potential base drag reduction. Also coupled with the technology being developed under the Drag Reducing Fumer Study (DRFS), design 8 could result in an extremely low drag projectile, especially since the base drag of the AR2 shape is approximately 60 percent of the overall drag. At the risk of being premature, it is conceivable that design 8, employing a drag-reducing fumer, could be utilized as both a FRS candidate and higher risk SAW candidate. Additional information on this concept is presented in Appendix B.

Also worthy of note are some of the extremely high twist rates required for a number of the designs (Appendix A). Some of these twist rates could be stretching the state-of-the-art in barrel manufacture. This problem area will be addressed with Rock Island Arsenal as the program progresses. In addition, the high twist rates required for stable launch of several FABRL designs may cause problem areas in bullet structural integrity, especially those with plastic engraving surfaces. However, a plastic bourrelet should offer reduced barrel erosion.

CONCLUSIONS

An analytical design study was undertaken, and results of this study illustrate the potential for a new, low-risk contender for the Future Rifle System (FRS). This new system, designated as Future Ammunition for Burst-Rifle Launch (FABRL), derives its maximum benefit from its very low impulse level of .80 pound-seconds. The impulse level of the FABRL would be significantly lower than the standard M16A1 system and comparable to the Serial Flechette Rifle (SFR) and Serial Bullet Rifle (SBR). In addition, the FABRL, employing a 37.1 grain AR2 shape projectile, would offer a lightweight system and the further possibility of employing lightweight cartridge case materials. However, extensive modifications to the M16A1 system would probably be required to make it compatable with the FABRL.

A number of basic projectile designs were generated during the study, three of which appear to be most promising for experimental development and evaluation. These three designs are the steel core/frangible jacket (design 5), steel core/plastic jacket (design 1), and the solid steel projectile (design 8) employing a drag-reducing tracer or fumer.

Design 8 would greatly improve the lower striking energies associated with the FABRL. Design 8 might also offer the potential for a common cartridge approach to both the FRS and the higher risk portion of the SAW program. This is discussed in greater detail in Appendix B.

RECOMMENDATIONS

1. Extensive hardware exploration of the FABRL concept should be pursued (currently programmed under Task 01 of Project A010 for FY 73 and FY 74). This exploration should include:

a. Expansion of the projectile design study in an attempt to generate additional projectile approaches.

b. Conducting a materials search and manufacturing experimental quantities of FABRL designs.

c. Conducting tests to evaluate FABRL accuracy, bullet integrity, trajectory, lethality, and penetration.

2. Given the data from 1 c above, and coupled with the data contained herein, an extensive systems analysis study should be conducted to assess the merits of the FABRL concept as a contender for the Future Rifle Program.

3. FABRL design 8, with a drag-reducing tracer (or fumer), should be evaluated for a common cartridge approach to both the FRS and higher risk portion of the SAW program.

APPENDIX A

Twist Rate Estimates

Barrel twist rates required for a gyroscopic stability factor of 1.50 were calculated for all of the FABRL designs. Standard techniques were used for the twist rate calculations.[4] The JSMOMNT computer program was used to calculate projectile weight, center of gravity, and moments of inertia.[5] The normal force coefficient and center of pressure for the 5.56 mm AR2 shape projectile were estimated from the values calculated by BRL.[1]

The standard formula for gyroscopic stability factor was modified (as shown below) to facilitate twist rate calculations.

$$T^2 = \frac{8\pi I_x^2}{\rho d^3 C_{M_\alpha} Sg I_y}$$

where:

T = Twist rate (inches/turn)

Sg = Gyroscopic stability factor (assumed equal to 1.50)

ρ = Air density (assumed equal to the standard density of 0.3 gr/cu in.)

d = Projectile diameter (assumed equal to 0.2235 in.)

I_x = Axial moment of inertia (gr-in.^{2})

I_y = Transverse moment of inertia (gr-in.^{2})

C_{M_α} = Static moment coefficient (per radian)

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[1] L. C. MacAllister, et al, "A Compendium of Ballistic Properties of Projectiles of Possible Interest in Small Arms," Ballistic Research Laboratories Report No. 1532, February 1971.

[4] "Design for Control of Projectile Flight Characteristics," Army Materiel Command Pamphlet AMCP 706-242, September 1966.

[5] A. J. Semeister, "Important Moments of General Axisymmetric Cartridge and Projectile Configurations," Frankford Arsenal Report R-2031, December 1971.

In addition, the static moment coefficient (C_{M_α}) was calculated from the formula shown below.

$$C_{M_\alpha} = C_{N_\alpha} (CP-CG)$$

where:

C_{N_α} = Normal force coefficient (estimated value of 2.78 per radian)

CP = Center of pressure in calibers from the base (estimated value of 2.42)

CG = Center of gravity in calibers from the base (calculated for each FABRL design)

The formula for calculating the twist rate required for the stable launch of each FABRL design now reduces to the following.

$$T = \frac{42.42\ I_x}{\sqrt{I_y\ (2.42 - CG)}}$$

The barrel twist rates required for stable launch of the FABRL designs are shown in Table A-I below.

TABLE A-I.
Twist Rates Required for Stable Launch of FABRL Designs

Design No.	Figure No.	Moment of Inertia (gr-in.²) I_x	I_y	Center of Gravity[a]	Twist Rate in./turn
1	3	0.1439	2.2430	1.643	4.6
2	4	0.1224	2.8618	2.037	5.0
3	5	0.1583	1.9850	2.294	13.4
4	6	0.2057	1.4141	1.144	6.5
5	7	0.1755	2.5014	1.751	5.8
6	8	0.0902	1.6327	1.518	3.2
7	9	0.1025	1.7662	1.553	3.6
8	10	0.2189	2.7929	2.083	9.6
9	11	0.2441	2.9279	1.951	8.8

[a] Calibers from base.

APPENDIX B

Drag-reducing Fumer Effects

This Appendix is presented to examine the effect of incorporating a drag-reducing fumer into the FABRL concept (design 8). A fumer is a method of reducing the base drag of a projectile by injecting the proper amount of heat and mass into the projectile base region during flight.

Fumer ammunition may be thought of as being somewhat analogous to tracer ammunition because heat and mass are ejected by the burning of some material in the base region to reduce the pressure gradient. However, there need be no illuminosity requirement, as with conventional tracer bullets, hence the name fumer.

To date, consistent base drag reductions (on the order of 50 percent over extended ranges) have been attained with certain fumer materials and projectile base configurations. A 75 percent reduction in base drag is estimated as a reasonable development goal. Higher levels of reduction are considered unrealistic (except, possibly for brief portions of the trajectory), and are therefore not presented.

Figures B-1 and B-2 illustrate velocity and striking energy as a function of range (from 0 to 500 meters) for the M193, the FABRL, and the FABRL, with a 50 and 75 percent base drag-reducing fumer effect. The 500-meter range is the expected range of interest for rifle engagements. The curves for the FABRL with the fumer effect were not adjusted to compensate for the negligible weight loss (approximately 2 grains when burnout occurs) due to the burning of the fumer material.

The 37.1-grain FABRL with a 75 percent reduction of base drag (Figure B-2) achieves a striking energy comparable to that of the M193 ball bullet at approximately 250 meters. Beyond this range, the lighter FABRL with 75 percent base drag reduction has better energy retention than the M193.

Figures B-3 and B-4 illustrate velocity and striking energy as a function of range (from 0 to 1100 meters) for the M193, 55 grain AR2 shape bullet (solid steel), the FABRL, and the FABRL with a 50 and

75 percent base drag reduction. The 1100-meter range is the usual range of interest for machine gun engagements. Figure B-3 illustrates that the FABRL with a 50 percent effective fumer has a ballistic coefficient virtually equal to that of the much heavier and identically shaped 55 grain AR2 projectile. Figure B-4 shows that the FABRL with 75 percent effective fumer has more striking energy beyond 670 meters than the 55 grain AR2 projectile.

Based upon experimental data, Ballistic Research Laboratories determined the striking energy the 55-grain copper plated steel AR2 shape projectile requires to penetrate a helmet with liner.[2] Figure B-4 illustrates that the FABRL with 75 percent, or even 50 percent, base drag reduction will penetrate a helmet with liner beyond 1100 meters.

From information on the FABRL contained in this report and certain other assumptions, a systems analysis study could be performed to assess the effectiveness of the FABRL with fumer in both the rifle and machine gun roles. However, a major trade off with the use of the FABRL as a common rifle-machine gun cartridge would be the introduction of a high engineering risk to the SAW project.*

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*Depending upon the extent of interest in a common cartridge, the AR2, .80 pound-second impulse system (52-grain bullet launched at 2509 fps), presented in Reference 1 might also be considered.

[2] M. J. Piddington, T. H. Oertel, E. L. Herr, and W. J. Bruchey, "Experimental Ballistic Properties of Selected Projectiles of Possible Interest in Small Arms" (U), Ballistic Research Laboratories Memorandum Report No. 2194, June 1972. (CONFIDENTIAL)

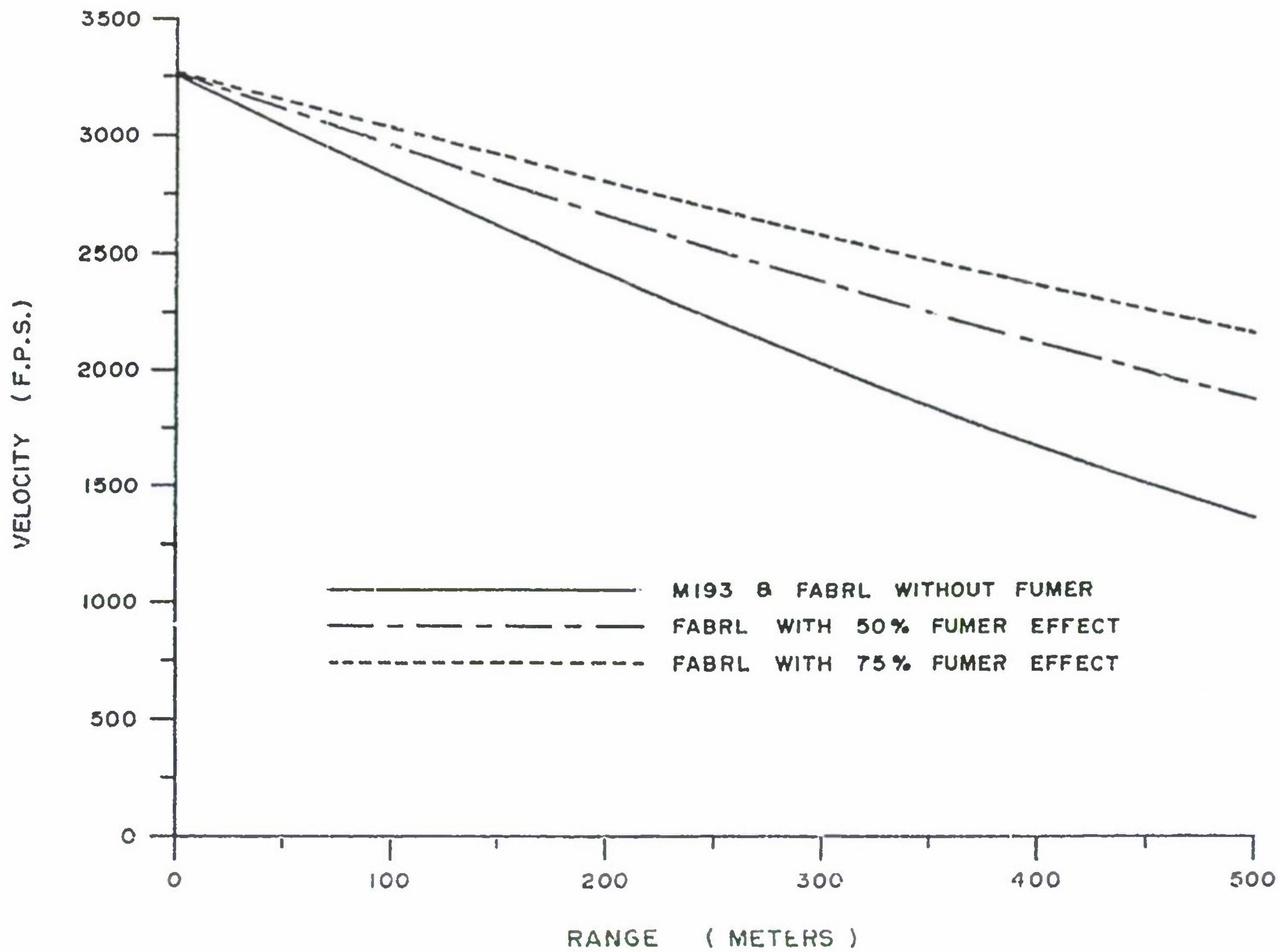

Figure B-1. Velocity vs Range

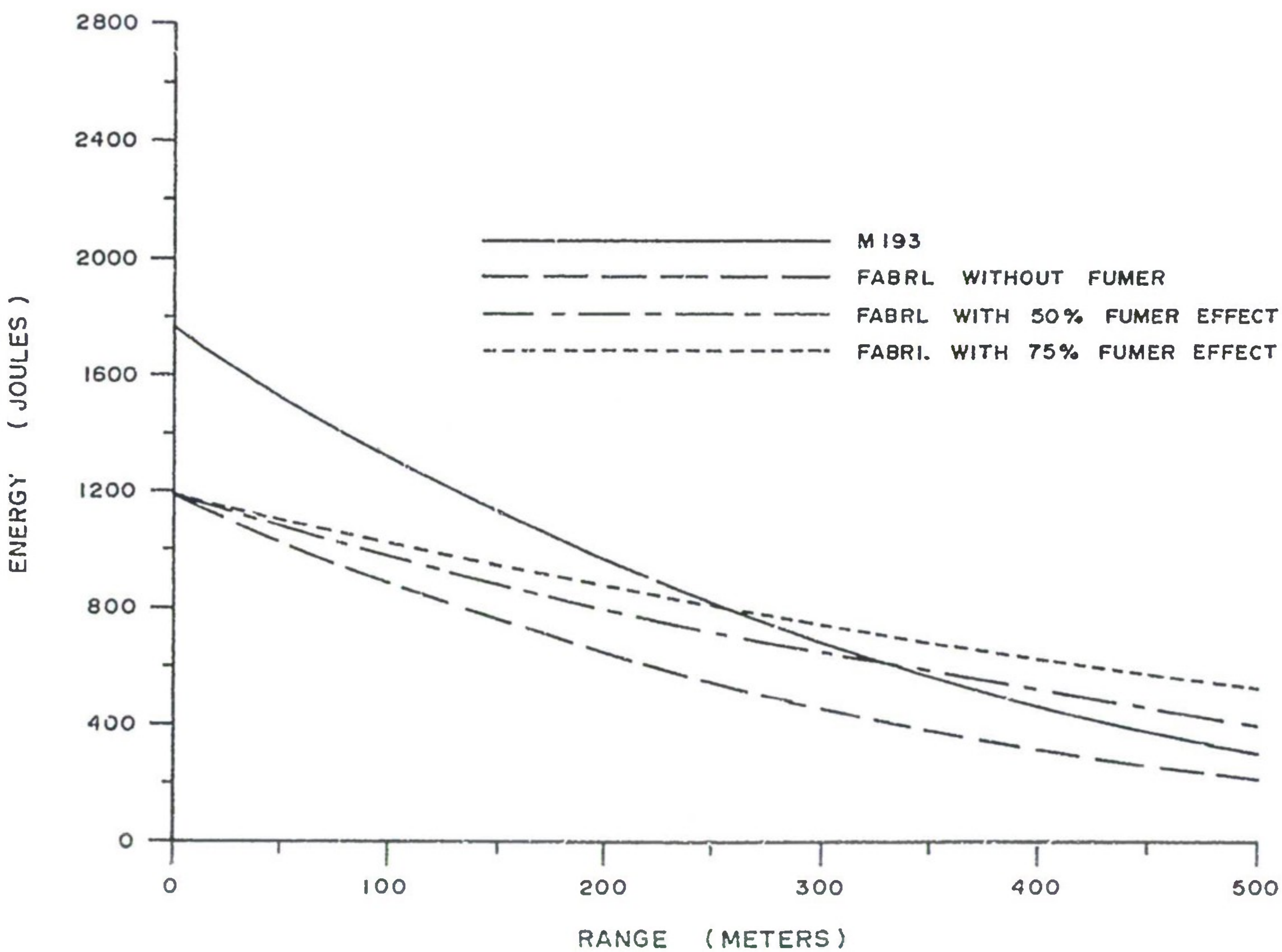

Figure B-2. Energy vs Range

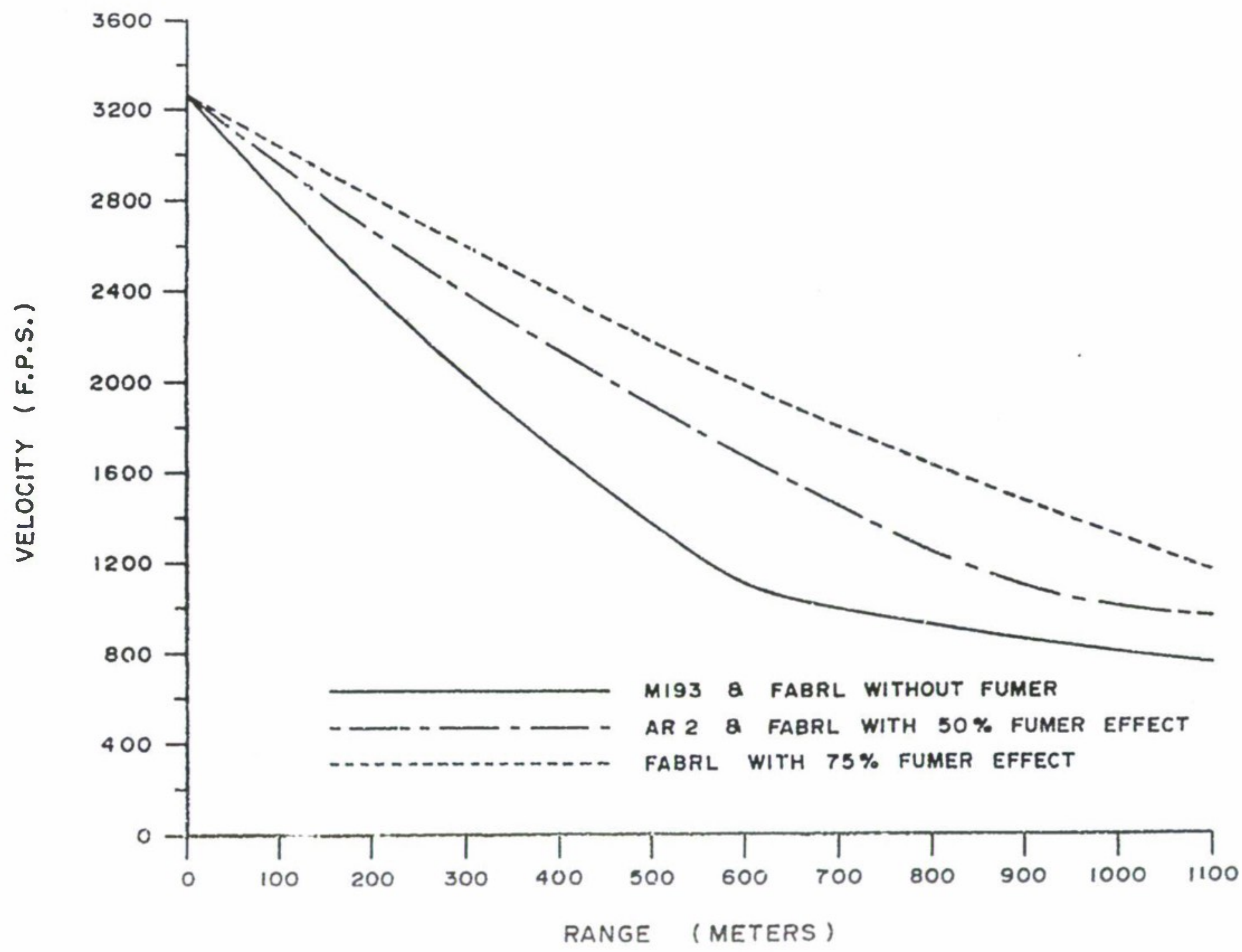

Figure B-3. Velocity vs Range

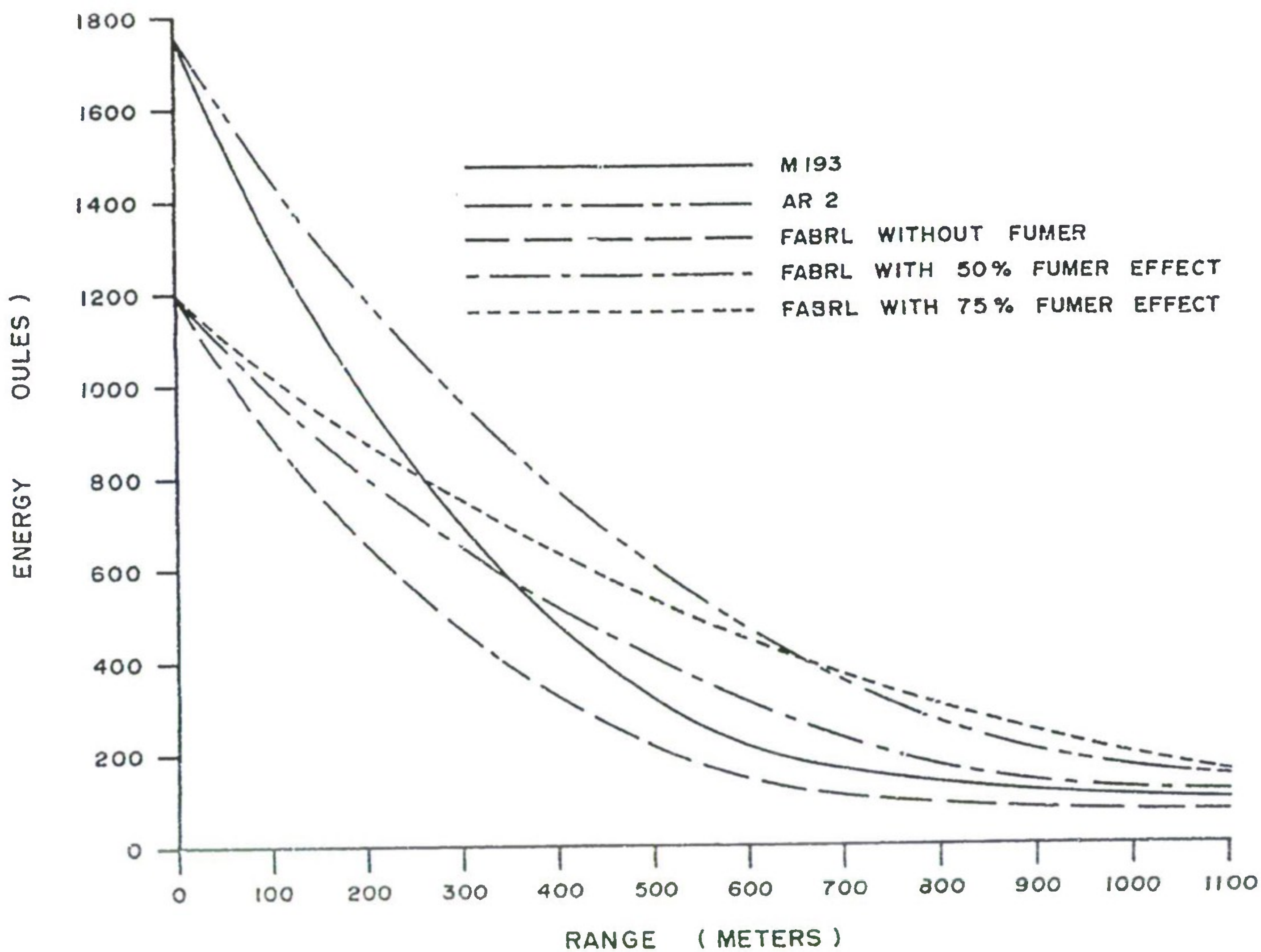

Figure B-4. Energy vs Range

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1. L. C. MacAllister, et al, "A Compendium of Ballistic Properties of Projectiles of Possible Interest in Small Arms," Ballistic Research Laboratories Report No. 1532, February 1971.

2. M. J. Piddington, T. H. Oertel, E. L. Herr, and W. J. Bruchey, "Experimental Ballistic Properties of Selected Projectiles of Possible Interest in Small Arms" (U), Ballistic Research Laboratories Memorandum Report No. 2194, June 1972. (CONFIDENTIAL)

3. "Interior Ballistics of Guns," Army Materiel Command Pamphlet AMCP 706-150, February 1965.

4. "Design for Control of Projectile Flight Characteristics," Army Materiel Command Pamphlet AMCP 706-242, September 1966.

5. A. J. Semeister, "Important Moments of General Axisymmetric Cartridge and Projectile Configurations," Frankford Arsenal Report R-2031, December 1971.